What is geothermal energy?

* Heat contained within the Earth that generates geological phenomena on a planetary scale
* Term presently used to indicate the part of the Earth’s heat that can/could be recovered and exploited by man
* Heat is generated within earth by radiogenic heat (heat generated by decay of isotopes)
* Other potential heat sources: primordial energy of planetary accretion
* Heat is in fact dissipated into space and earth is slowly cooling down
* Geothermal energy is renewable and sustainable
  + ***Renewable*** 🡪property of geothermal energy. Justified because the rate of energy recharge takes place in the same time scale as the utilization of the resource
  + ***Sustainable*** 🡪 how it is utilized. Must be used so that resource can be created faster than it is being depleted, and needs of current generations should not compromise the need in future generations

Heat content of earth

* Entire earth = 12.6 x 1024 MJ (Armstead 1983)
* Crust = 5.4 x 1021 MJ (Armstead 1983)
* Temp at core about 4000°C
* Only a fraction of this energy can be utilized
* Utilization limited to areas where geologic conditions permit a carrier (water, steam) to transfer the heat from deep hot zones to the surface
* Exploitation of e.g. natural steam 🡪 used for mechanical energy, electrical energy

Common worldwide uses

* Nonelectrical
  + Heat pumps (34.80%), bathing (26.20%), space heating (21.62%), greenhouses (8.22%), aquaculture (3.93%), industrial processes (3.13%) (Lund and Freeston, 2001)
* Electrical
  + 47% world total installed geothermal power in 2000 in developing countries
  + Canada: 377.6 MWt installed power year and 1023 TJ/yr energy usage in year 2000 (Lund and Freeston 2001)

Nature of Geothermal Resources

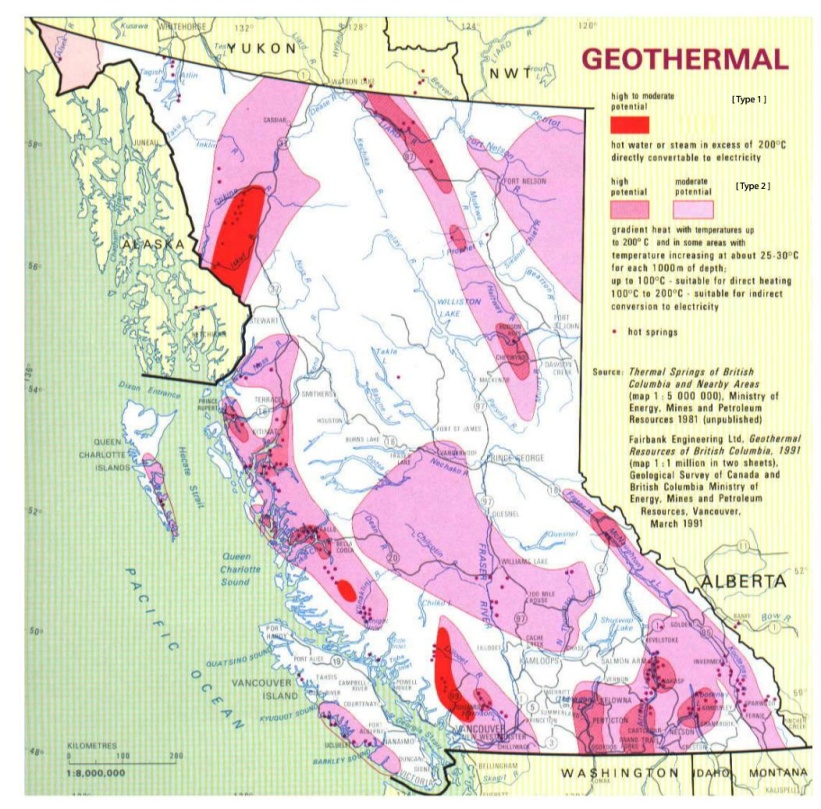
* “Earth’s thermal engine” 🡪 the ***geothermal gradient*** expresses increase of temperature with depth into the earth’s crust
* Temperature difference between deep hot zones and shallow cool zones generates a conductive heat flow (Convective movement of geothermal energy causes plate tectonic movement)
* This tends to create uniform conditions, but due to natural phenomena this is often never the case
* ***Geothermal system****:* ‘*convecting water in the upper crust of the Earth, which, in a confined*

*space, transfers heat from a heat source to a heat sink, usually the free surface*’(Hochstein, 1990).

* Requires three main elements: heat source, reservoir, fluid
  + ***Heat source*:** can be shallow (10-15 km) and high heat (>600°C) or Earth’s normal temp
  + ***Reservoir***: volume of hot permeable rocks from which circulating fluids can obtain heat
  + ***Geothermal fluid***: vapour or liquid water, which often carries other chemicals and gases
* Mechanism of geothermal systems is largely fluid convection

Geographic Requirements

* Found in areas with normal/slightly above normal geothermal gradients, meaning areas with high heat flow (especially around e.g. plate margins)
* Western Canada has extensive geothermal potential (<http://www.cangea.ca/what-is-geothermal/>)



* In BC, high temperature potential areas are mainly located by the coastal mountains (<http://www.em.gov.bc.ca/geothermal/geothermalrights.htm>)
* Geothermal fields mainly localized around young areas of tectonism, volcanism, and along active plate boundaries or over mantle hot spots (Barbier 2001)

Geologic Requirements

* at present drilling technology we are able to harness the highest quality geothermal power, which is located closest to the earth’s surface (<http://www.cangea.ca/what-is-geothermal/>)
* drilling costs increase exponentially with depth (<http://www.cangea.ca/what-is-geothermal/>)
* hot dry rock in the future may be exploited for geothermal energy... will look more into this later (Bernier 2001)

Environmental Requirements

* ***Injection wells***- sites where e.g. geothermal fluids extracted from a reservoir are injected back into reservoir after utilization
  + reduces impact of environment and geologic impacts of extracting geothermal energy
  + Integrates natural and artificial recharge
  + Also helps replenish/maintain old/exhausted geothermal fields (e.g. The Geysers field in California drastically reduced in production due to lack of fluids)
* Major environmental impact of concern is pollution of air and bodies of water (Barbier 2001)
* Emissions of geothermal plants are well below emissions in comparison to, for example, coal-fired plants (Barbier 2001)
  + Excess steam from flash geothermal plants (open systems\*) can contain non-condensable gases e.g. CO2, H2S, NH3, CH4, N2 and H2 (emissions are site-specific)
  + H2S is oxidised to sulfur dioxide and then to sulfuric acid, and may cause acid rain
  + Chemicals in steam leave atmosphere through rain and could then leach into soil and vegetation, contaminating them.
  + Surface water contamination and aquatic life impact are also concerns
* If fluid is passed through heat exchanger and reinjected without exposure to atmosphere should not have any fluid or gas discharge to environment (Bernier 2001)
* Reinjection of water into reservoir may induce seismic activity (Bernier 2001)
  + Geothermal reservoirs are located in geologically unstable areas of the earth’s crust to begin with
  + Reinjection of water reduces rock stress, loosens vertical faults, and triggers release of tectonic stress
  + This may actually have a positive effect because it favours progressive release of stress (therefore higher number of low magnitude events) rather than one instantaneous release
* Land subsidence, which is the sinking of land level, may result because as fluids are removed, pore pressure is reduced in the reservoir rock and the ground tends to subside under the weight of the rock above (Bernier 2001)

Classifying Geothermal Resources

* ***Enthalpy*** is a common criterion for classifying geothermal resources (enthalpy of the geothermal fluids that are heat carriers)
* Enthalpy is ≈ proportional to temp. expresses heat content of the fluids and therefore their ‘value’

Assessing Sustainability (Evans et al 2009)

* Price of electricity generation
* GHG emissions?
* Availability and technological limitations
* Land use
* Social impacts
* Water consumption

**Sources** (Obviously not in proper format yet..)

HOCHSTEIN, M.P., 1990. Classification and assessment of geothermal resources. In:

Dickson, M.H. and Fanelli, M., *eds*., *Small Geothermal Resources: A Guide to*

*Development and Utilization*, UNITAR, New York, pp. 31—57.

ARMSTEAD, H.C.H., 1983. *Geothermal Energy*. E. & F. N. Spon, London, 404 pp.

LUND, J. W., and FREESTON, D., 2001. World-wide direct uses of geothermal energy

2000. *Geothermics* **30**, 29- 68.

Assessment of sustainability indicators for renewable energy technologies

Annette Evans, Vladimir Strezov \*, Tim J. Evans

*Renewable and Sustainable Energy Reviews*

13 (2009): 1082-1088

<http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6VMY-4SBHBJ7-5-5&_cdi=6163&_user=1067350&_orig=search&_coverDate=06%2F30%2F2009&_sk=999869994&view=c&wchp=dGLzVlz-zSkzk&md5=d7ffc00f3595601da8d9cfc3f1cefc9e&ie=/sdarticle.pdf>

Geothermal energy technology and current status: an overview

Enrico Barbier

[**Renewable and Sustainable Energy Reviews**](http://www.sciencedirect.com/science/journal/13640321)  
[Volume 6, Issues 1-2](http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%236163%232002%23999939998%23321557%23FLA%23&_cdi=6163&_pubType=J&view=c&_auth=y&_acct=C000051241&_version=1&_urlVersion=0&_userid=1067350&md5=f7ccbfceeb4c0fbb43c2afa1177425ed), 2002, Pages 3-65 [doi:10.1016/S1364-0321(02)00002-3](http://dx.doi.org/10.1016/S1364-0321(02)00002-3" \t "doilink)

Unless otherwise stated all info came from this source:

* <http://tecnet.pte.enel.it/depositi/tecnet/bestpractice/277/36598-Geothermal_Energy.zip.dir/Geothermal_Energy.en.pdf>
* Title: “What is geothermal energy?”
* Authors: Mary H. Dickinson and Mario Fanelli
* *Istituto di Geoscienze e Georisorse, CNR , Pisa, Italy*
* *Date: February 2004*